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INFLUENCE OF CARBON AND OXYGEN ON SOME EXPLORATORY ULTRAHIGH-STRENGTH ALPHA-BETA TITANIUM ALLOYS

Technical Report by

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ABSTRACT

An examination was made of the alloys formulated and studied at New York University under Contract DA-30-069-ORD-3690 to determine the effect of modifying the oxygen and carbon contents normally employed in titanium alloys on their mechanical properties.

A total of 51 exploratory ultrahigh-strength alpha-beta titanium alloys were scrutinized. The results indicated that the alloys with low oxygen content, approximately 0.03% to 0.05% by weight, generally possessed lower yield strengths but good ductility and toughness compared to the alloys with higher oxygen contents at 200,000 psi strength levels. The alloys with the lower oxygen content also responded more readily to the 1150 F aging treatment, causing the yield strength to decrease more substantially than those alloys in the higher oxygen content range of 0.09% to 0.11%. The alloys containing 0.04% to 0.08% oxygen and 0.05% to 0.09% carbon exhibited no definite or predictable change in mechanical properties due to the modified oxygen and carbon. The influence of carbon on ductility and toughness was considerably less than that of oxygen. The optimum alloy, No. 7, containing 0.12% carbon and 0.11% oxygen, displayed a yield strength of approximately 220,000 psi, elongation of 11.9%, and impact strength of 5.9 ft-lb at 1150 F aging temperature.

The most effective oxygen plus carbon content for each alloy which would develop the optimum mechanical properties appeared to depend on the alloy and the specified yield strength range.

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INTRODUCTION

Studies[1] in the development of tough, high-strength titanium base alloys with yield strength levels in excess of 200,000 psi have contributed to the possibility of revising the existing philosophies pertaining to the behavior of carbon and oxygen for attainment of high strength levels. The effects of these interstitial elements on the mechanical properties of unalloyed titanium and some less complex titanium alloys have been investigated[2,3] and the results have indicated that these elements, when used in certain increasing quantities, will increase strength but decrease ductility and toughness.

The interstitial elements carbon and oxygen, being alpha-stabilizing, dissolve preferentially in the hexagonal close-packed phase and raise the beta transus temperature of the titanium alloy. It has been reported[2,3] that oxygen, whose solubility in alpha titanium is much more extensive than that of carbon, has a hardening effect on unalloyed titanium and its alloys, where two parts of oxygen approximate the same hardening effect as three parts of carbon. However, the results of some investigations on the behavior of oxygen and carbon in the presence of various substitutional elements in complex high-strength titanium alloys have shown that the same relationship does not exist. Studies have established[2,3] that optimum carbon and oxygen levels for titanium alloys depend on the relationship between the concentration of these interstitials and the type and concentration of the substitutional alloying elements present in the alloys. This is shown[2] in the Ti-Sn system where oxygen is a greater strengthener than carbon, while in the Ti-Al system carbon is a greater strengthener than oxygen, and in the Ti-V system similar effects are seen by both elements. No such conclusion has been established for an alloy containing Al, V, and Sn in major proportions such as found in the high-strength Ti-Al-Sn-V-Zr-Fe-Cu system.

Some discrepancies still exist as to the interstitial level which will enhance mechanical properties for a specific substitutional alloy composition. The current commercial interstitial levels for alloys having yield strengths above 150,000 psi, especially in alpha-beta titanium alloys, are usually achieved when a combination of oxygen, carbon, and nitrogen, total approximately 0.25 weight percent. Of this total, the nitrogen content ranges from 0.005 to 0.02%, the carbon 0.02 to 0.05%, and the oxygen the remainder. Past investigations by Farrar and Margolin[1] have indicated that in order to obtain optimum mechanical properties at high strength levels, the interstitial content of oxygen and carbon could be at a lower level than that generally accepted, provided the proper levels of certain substitutional elements such as Al, V, Sn, Zr, Fe, Cu were maintained. This conclusion was based on their studies which disclosed that an increase in content of either oxygen or carbon from a base level of approximately 0.08% oxygen and 0.015% carbon quite markedly reduced the ductility levels but raised the yield and ultimate strengths; however, raising substitutional element concentration levels alone, in order to increase strength, was less detrimental to ductility. Also, they have disclosed that, when up to 0.1% carbon was added to certain high-strength alpha-beta titanium alloys having over 200,000 psi yield strength, substantial increases in yield strength were obtained with considerably less loss in ductility than when oxygen alone was used to produce a similar strength increase.

It is the purpose of this paper to supplement existing information on the behavior of oxygen and carbon in the presence of certain substitutional elements in titanium by reporting the effects of varying the concentration of these interstitials on the mechanical properties of a series of high-strength titanium alloys stemming from the Ti-Al-V-Sn-Zr-Fe-Cu system.

MATERIALS AND EXPERIMENTAL PROCEDURES

Test Ingots

The titanium compositions selected for investigation (Table I) were employed in recent programs conducted at New York University under AMMRC sponsorship. These alloys were double vacuum melted as eight-pound ingots.

Specimen Fabrication

After a machining operation to remove surface imperfections, the ingots were forged into one-half-inch-diameter bars in a sequence of operations described in Reference 4. The forging temperatures were based on the beta transus temperatures obtained according to the procedures described in that work.

The one-half-inch-diameter forged bars were cut into tensile and Charpy blanks. These test specimen blanks were rough machined to eliminate the forged surfaces and then subjected to a prescribed heat treatment of solution treating and aging. Various temperatures and times were used during the solution treating and aging[5,6,7,8] depending on the availability of test specimens. This report discusses the results obtained for specimens heat treated at one solution temperature, 125 F below the beta transus temperature where available (see Table II), and aged at temperatures of 1050 F and 1150 F for one hour.

The heat-treated specimen blanks were machined into standard 0.252-inch-diameter threaded tensile bars with a 1.00-inch gage length and standard 0.394-inch square by 2.156-inch-long V-notched impact bars with a 0.010-inch radius notch.

Tensile strength, yield strength, elongation, and reduction of area values were obtained from the tests at a strain rate in the range of 0.003 to 0.005 in./in./min. The yield strength results obtained at 0.1 percent offset, elongation, and Charpy impact data obtained at -40 F are discussed in this report.

RESULTS AND DISCUSSION

Most fundamental investigations[2,3] of less complex titanium alloy systems have concluded that oxygen, when used in small amounts, increases strength but generally decreases ductility and toughness while carbon will tend to increase

Table I. CHEMICAL ANALYSIS OF ALLOYS WITH VARYING CARBON PLUS OXYGEN LEVELS

	Elements (weight %)												(ppm)
Alloy	Al	V	Sn	Cu	Fe	Zr	Cr	Mo	Ni	C	O	N	H
a. Carbon + Oxygen Level of 0.04% to 0.10%													
2	6.70	6.66	1.78	0.80	1.03	2.61	0.89	0.90	-	0.04	0.036	0.009	14.9
4	6.15	5.25	1.70	1.01	1.15	5.93	1.00	1.00	-	.04	.036	.006	25.5
6X	5.86	6.10	1.88	0.98	0.85	2.36	-	-	-	.03	.033	.008	19.9
10	5.96	6.28	1.73	2.02	1.07	2.67	-	-	-	.03	.042	.005	18.3
12	6.23	5.93	1.61	2.02	1.13	6.10	-	-	-	.04	.033	.005	33.7
14	6.43	5.90	1.40	2.13	1.10	-	0.87	-	-	.06	.036	.004	31.6
16	5.44	6.20	2.06	2.00	1.11	2.78	0.88	-	-	.01	.034	.010	25.5
18	6.46	6.24	1.67	2.00	1.06	6.07	1.09	-	-	.04	.034	.004	30.3
20	6.29	6.03	1.73	1.02	1.04	-	0.85	1.18	-	.04	.041	.006	17.1
22	6.43	5.71	1.67	0.83	1.06	3.04	1.08	1.12	-	.04	.035	.006	19.5
24	5.94	6.20	1.61	0.97	1.06	5.78	0.99	0.98	-	.04	.036	.007	28.5
26	6.10	5.98	2.00	1.72	1.03	2.92	0.92	1.35	-	.01	.036	.009	32.4
28	5.30	5.28	2.80	2.02	0.88	2.89	1.13	-	-	.01	.034	.010	19.2
30	6.17	6.04	2.42	1.91	1.02	2.74	0.98	1.05	-	.05	.028	.005	22.2
31	6.05	4.75	1.95	-	1.03	3.02	0.90	0.98	0.89	.03	.051	.007	46
32	6.25	4.84	2.02	-	1.03	2.89	0.46	1.47	0.89	.03	.058	.005	37
39	6.19	4.71	2.25	-	0.95	2.96	-	1.96	0.90	.03	.053	.005	17
41	5.90	5.95	2.07	0.96	1.03	2.97	-	-	-	.05	.038	.077	6
49	4.90	8.02	2.36	0.90	1.15	2.96	-	-	-	.03	.048	.006	25
56*	5.98	5.95	2.04	-	1.23	2.92	-	-	-	.03	.049	.011	9
b. Carbon + Oxygen Level of 0.10% to 0.125%													
3	6.07	4.82	1.58	0.96	0.91	5.72	1.03	1.12	-	0.03	0.087	0.009	22.2
5	5.84	5.80	2.00	0.94	0.83	2.45	-	-	-	.03	.090	.024	20.6
11	5.70	5.72	1.61	1.88	1.02	5.92	-	-	-	.02	.096	.014	8.8
13	6.42	5.58	2.00	2.03	0.86	-	1.24	-	-	.01	.098	.016	29.9
15	5.50	5.95	1.82	2.04	1.15	3.06	1.24	-	-	.03	.092	.015	15.8
21	5.84	5.82	1.76	0.97	0.83	2.77	1.20	1.03	-	.01	.102	.016	35.8
25	6.25	6.16	1.94	2.05	0.96	2.83	1.09	1.47	-	.02	.094	.017	38.0
27	5.54	6.09	2.29	1.84	1.13	2.82	0.85	-	-	.01	.091	.006	22.1
35	5.85	5.00	2.04	-	0.96	3.06	-	-	0.96	.08	.028	.004	17
37	6.10	5.90	2.10	-	0.96	2.95	-	-	1.04	.08	.043	.008	6
40	6.10	5.94	2.10	0.44	1.26	2.98	-	-	0.46	.07	.054	.007	6
47	6.00	5.93	2.36	0.77	1.02	-	0.46	0.52	-	.03	.072	.011	11
54+	6.14	6.25	2.10	0.91	1.05	3.00	-	-	-	.03	.070	.005	15
55	4.07	8.42	1.95	1.00	0.95	2.92	-	-	-	.03	.081	.032	32
c. Carbon + Oxygen Level of 0.125% to 0.150%													
1	6.19	5.25	2.06	0.90	1.17	2.72	1.29	1.05	-	0.04	0.093	0.016	9.5
8	5.96	6.02	2.00	0.93	1.02	2.41	-	-	-	.11	.036	.016	21.9
9	6.05	5.68	2.17	2.17	1.02	2.82	-	-	-	.02	.113	.014	15.6
17	6.53	5.87	1.49	2.09	1.03	5.86	0.90	-	-	.05	.094	.004	17.6
19	5.34	6.02	1.73	0.80	1.00	-	0.82	0.93	-	.03	.113	.015	24.7
23	6.38	5.83	1.94	0.88	1.15	5.74	1.03	0.92	-	.04	.092	.010	19.2
29	5.95	5.86	1.85	2.08	1.08	2.64	1.09	1.20	-	.05	.092	.010	24.3
34	5.95	5.05	2.04	-	1.04	3.04	-	-	1.06	.08	.051	.014	33
38	5.90	5.90	1.95	-	0.96	3.02	-	-	0.98	.11	.037	.005	25
43	5.94	6.03	2.02	1.02	1.03	3.03	-	-	-	.08	.055	.006	8
50	5.73	5.85	2.40	0.80	1.17	3.02	1.00	0.90	-	.08	.070	.004	16
d. Carbon + Oxygen Level of 0.150% to 0.250%													
7	5.94	6.06	1.88	0.96	1.09	2.34	-	-	-	0.12	0.114	0.015	21.7
33	6.14	5.11	2.04	-	1.01	2.98	0.90	-	0.90	.09	.076	.003	27
36	5.14	5.40	2.10	-	1.03	4.05	-	-	1.01	.09	.064	.009	4
42	5.90	5.90	2.04	1.04	0.96	3.04	-	-	-	.09	.061	.008	2
44	5.89	6.10	2.07	0.97	1.03	3.00	-	-	-	.16	.056	.005	9
45	5.97	5.95	2.02	1.03	1.01	2.98	-	-	-	.18	.066	.008	7
46	6.06	5.27	2.36	0.76	1.01	3.04	0.90	1.04	-	.15	.063	.005	16
48	6.13	6.17	2.58	1.01	0.95	-	0.46	0.52	-	.09	.063	.011	11

*Contains 0.40 Si
+Contains 0.034 B

Table II. BETA TRANSUS AND SOLUTION TEMPERATURES EMPLOYED

Alloy	Temperature (deg F)		Alloy	Temperature (deg F)	
	Beta Transus	Solution		Beta Transus	Solution
2	1575	1450	27	1650	1525
4	1550	1425	35	1700	1575
6X	1600	1475	37	1700	1575
10	1575	1450	40	167[illegible]	1550
12	1575	1450	47	1625	1500
14	1575	1450	54	1650	1525
16	1575	1450	55	1500	1400†
18	1550	1425	1	1625	1500
20	1600	1475	8	1700	1575
22	1550	1425	9	1650	1525
24	1550	1425	17	1575	1450
26	1575	1450	19	1650	1525
28	1575	1450	23	1575	1450
30	1600	1475	29	1600	1475
32	1600	1475	34	1725	1600
39	1600	1475	38	1725	1600
41	1650	1525	43	1650	1525
49	1550	1400*	50	1650	1525
56	1750	1575*	7	1700	1575
3	1575	1450	33	1650	1525
5	1650	1525	36	1650	1575†
11	1600	1475	42	1675	1550
13	1625	1500	44	1675	1550
15	1600	1475	45	1675	1550
21	1600	1475	46	1675	1550
25	1600	1475	48	1700	1575
31	1650	1525			

*More than 125 F difference
†Less than 125 F difference

ductility. This is shown in Figure 1, which indicates that as substitutional elements are added, the degree to which carbon and oxygen will react becomes a function of the individual substitutional element. An attempt to show the influence of these interstitials on a more complex high-strength titanium system containing a combination of the elements Al, V, Sn plus several others such as Zr, Fe, and Cu is presented in Figure 2. In this figure, Farrar and Margolin illustrate from some previous studies[1] that there can be more than one range of carbon and oxygen content which will increase mechanical properties. The significance of this data demonstrates the importance of specifying a strength range.

In light of the limited availability of data pertaining to the effect of these interstitials on polyphase titanium alloys, an examination was conducted to study their effects on the high-strength titanium system Ti-Al-V-Sn-Zr-Fe-Cr. The alloys under consideration were selected from two programs being conducted at New York University and sponsored by AMMRC, dealing with

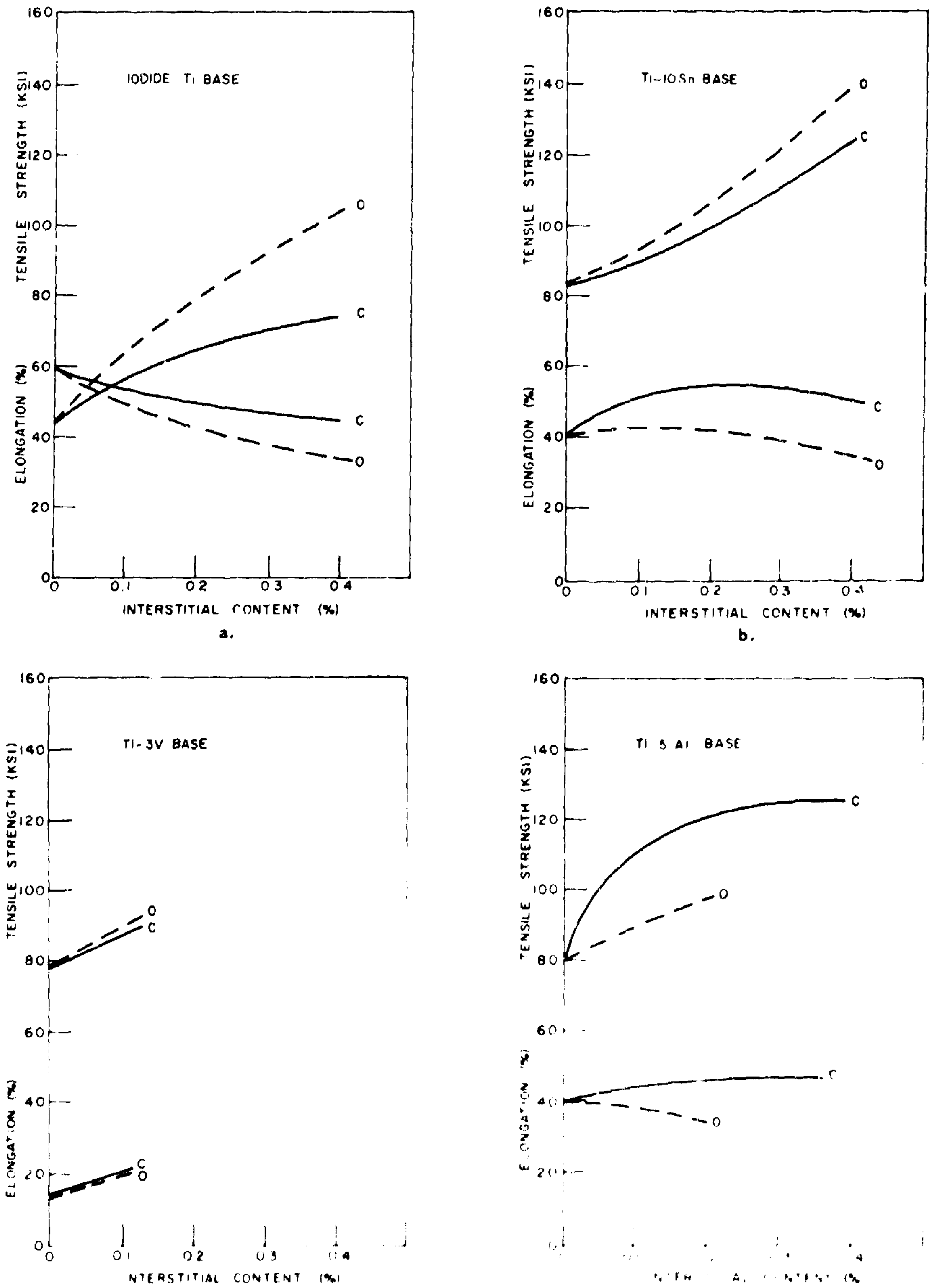

Figure 1. THE EFFECT OF OXYGEN AND CARBON ON VARIOUS TITANIUM ALLOYS (Ref. 3)

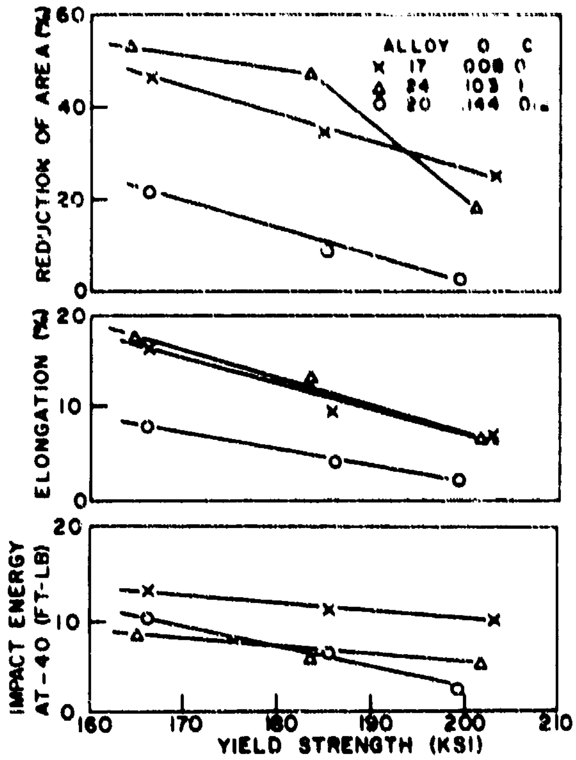

Figure 2. THE EFFECT OF OXYGEN AND CARBON ON Ti-5.25Al-5.5V-2Sn-0.9Fe-1Cu-4Zr ALLOY. (Ref. 10)

the development of high-strength alpha-beta titanium alloy. The alloys, numbered up to 30, stressed higher purity in oxygen content than the higher numbered alloys which came from the later program. The chemical analyses of all the alloys are listed in Table I and, as can be seen, the alloys are formulated primarily from the Ti-Al-V-Sn-Zr-Fe-Cu system with some slight modifications. In the alloys up to number 30, the nominal analyses for carbon and oxygen were scheduled to range between two levels. The lower level for the oxygen was from approximately 0.03% to 0.05%, the higher level was from approximately 0.09% to 0.11%. The carbon was kept between 0.01% to 0.05% in all but three alloys. Two of the alloys, 7 and 8, were purposely alloyed with higher carbon in order to study the effect of this addition. In the alloys numbered higher than 30, the oxygen content ranged from approximately 0.03 to 0.09% while the carbon ranged from 0.03% to 0.18%. These carbon and oxygen contents were decided upon from the results of the first program which gave indications of some advantages for using higher carbon. The mechanical properties of all the alloys are listed in Table A-I of the Appendix.

To show the relative position of the alloys as a function of their mechanical properties versus interstitial content (carbon plus oxygen only), the alloys were divided into four interstitial ranges, 0.03% to 0.10%, 0.10% to 0.125%, 0.125% to 0.150%, and 0.150% to 0.250% as indicated in Table A-Ia through A-Id and plotted as illustrated in Figures 3 and 4. The plotted data used is the result of a solution temperature of 125 F below the beta transus for all alloys except three as listed in Table II. The data in Table A-I is the average of at least two values wherever possible. A complete tabulation of the properties obtained at these and other solution temperatures for all the alloys are found in References 5 through 8. The properties reported at the aging temperatures of 1050 F and 1150 F represented generally the optimum values of the alloys with yield strengths as close to and over 200,000 psi, with specified ductility and toughness as indicated in Army Specification MIL-T-46038.[9]

As previously mentioned, the interstitials under consideration are carbon and oxygen. Nitrogen has been recognized to contain a pronounced strengthening effect on titanium; however, for these studies its effect is not being analyzed.

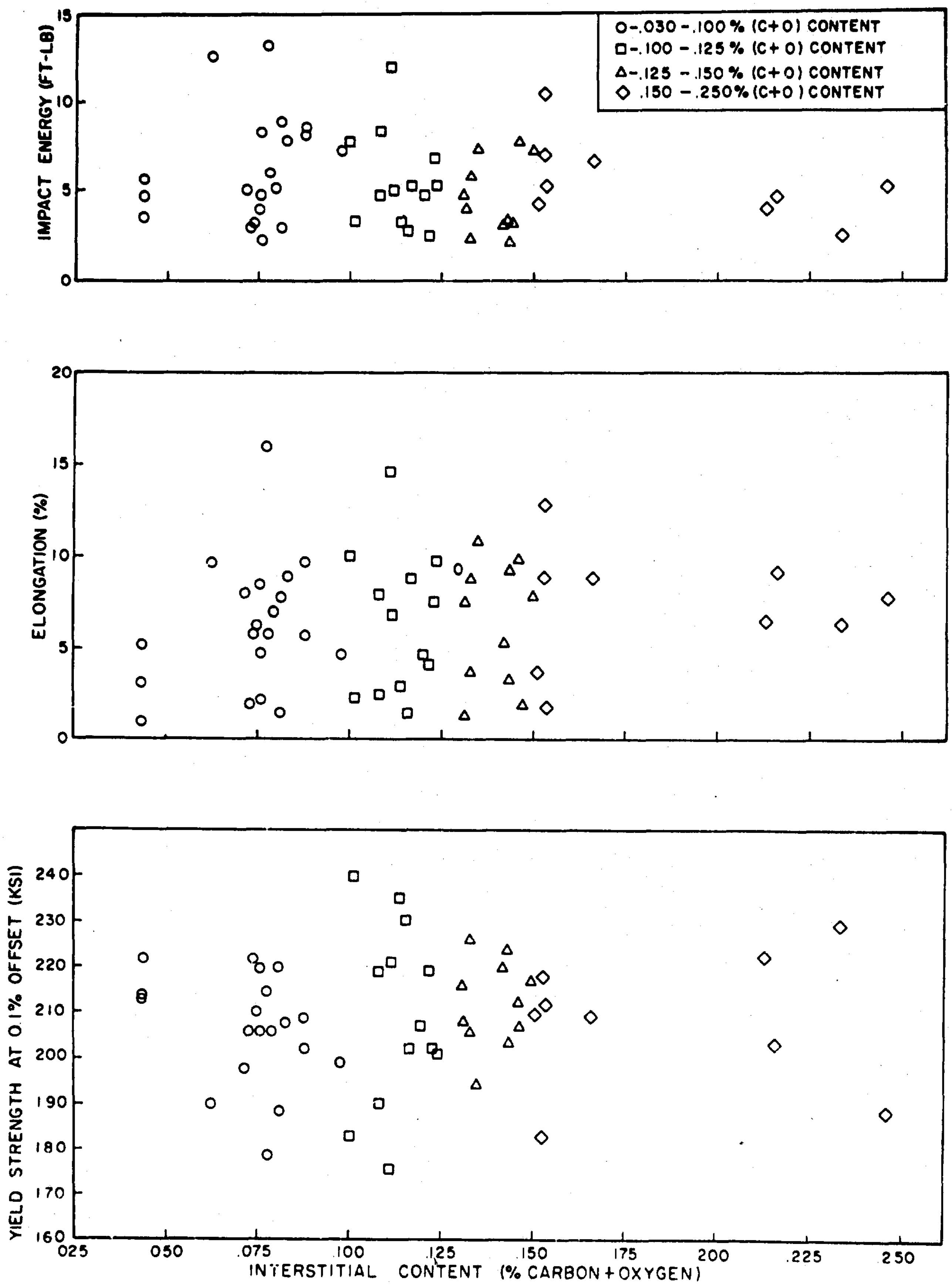

Figure 3. MECHANICAL PROPERTIES VERSUS INTERSTITIAL CONTENT AT 1050 F AGING TEMPERATURE

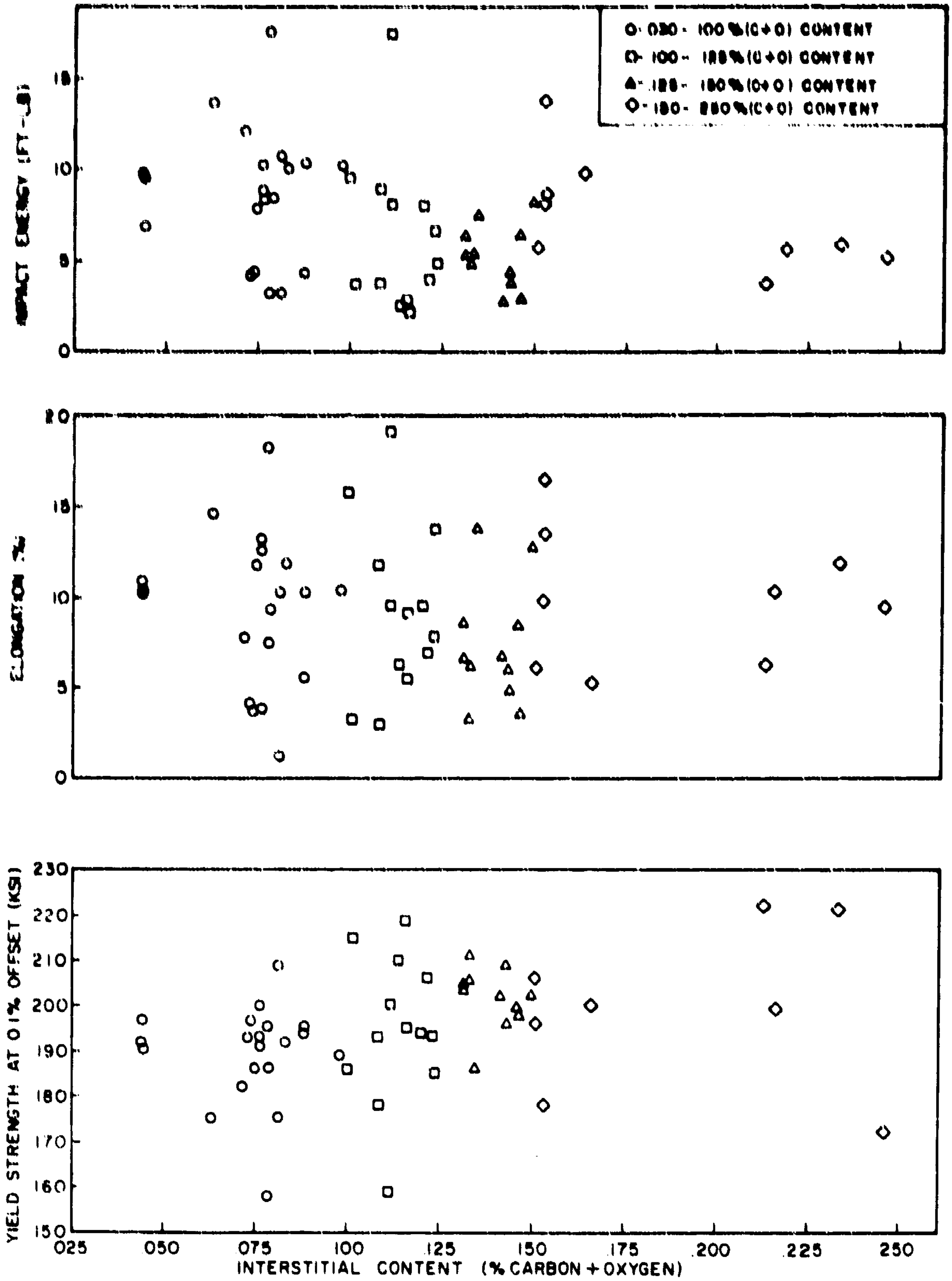

Figure 4. MECHANICAL PROPERTIES VERSUS INTERSTITIAL CONTENT AT 1150 F AGING TEMPERATURE

The alloys listed in Table Ia comprise the low interstitial level which ranges from approximately 0.04% to 0.10% as compared with normal commercial composition of approximately 0.10% to 0.25%. In this range the alloys have an oxygen content of approximately 0.03% to 0.05% and a carbon content of 0.01% to 0.05% with No. 14 containing 0.06%. The purpose of investigating these alloys with the low interstitial level was in anticipation of enhancing the strength of the base alloy by alloying with substitutional elements, and increasing the ductility by the use of a lower interstitial content than is usually employed.

Scrutinizing Figures 3 and 4, it can be seen that the majority of the alloys in this interstitial range possessed yield strengths in the 200,000 to 220,000 psi range when aged at 1050 F and decreased to the 180,000 to 200,000 psi range when aged at 1150 F. These values were comparable to the majority of the other alloys listed in Tables Ib, c, and d at 1050 F aging temperature, while at 1150 F aging temperature the high purity alloys showed less scatter and as a group possessed slightly lower strength; however, the ductility and toughness values were generally well in excess of that required by Army Specification MIL-T-46038. The other interstitial levels possessed strength levels approximately 10,000 psi higher, with acceptable ductility, than the lowest interstitial group, but as a group the toughness appeared low for this strength level as seen in Figure 4. Here, it is clearly seen how the alloys with the higher interstitial content in the 190,000 to 210,000 psi yield strength range, have lower impact strengths than similar alloys with lower interstitial content at the same strength range. The toughness should average between 6 to 7 ft-lb for this strength range, as specified under MIL-T-46038.

The data contained in Figures 3 and 4 were resolved further in order to examine the individual effects of carbon and oxygen as shown in Figure 5. In Figure 5a the mechanical property values (Table A-I) are plotted against the percentage of carbon present in the alloys aged at 1050 F and 1150 F. The curves are drawn between points which appeared most "reasonable". Since the data representing some of the points were based on only one result, there was some question as to the validity of the position of these individual points, and some were omitted from the averages even though they appear in the tables.

It is interesting to note in Figure 5a that there appears to be a decrease in strength as the carbon is increased between 0.05% and 0.08% and then an upward trend in strength as the carbon is increased to 0.12%, followed by a sharp decline with further carbon additions. The ductility increases to the 0.05% to 0.08% carbon range and then tends to level off while the toughness follows similar trends only somewhat more moderately. The increase in carbon only moderately affected ductility and toughness.

In contrast to this behavior, mechanical properties plotted against percentage oxygen as shown in Figure 5b (Table A-II) indicate a less drastic pattern. Aside from a minima between 0.04% to 0.06% oxygen range in the yield strength curves, there exists a continuous increase in yield strength as the oxygen percentage increases. Being consistent with this, the ductility and

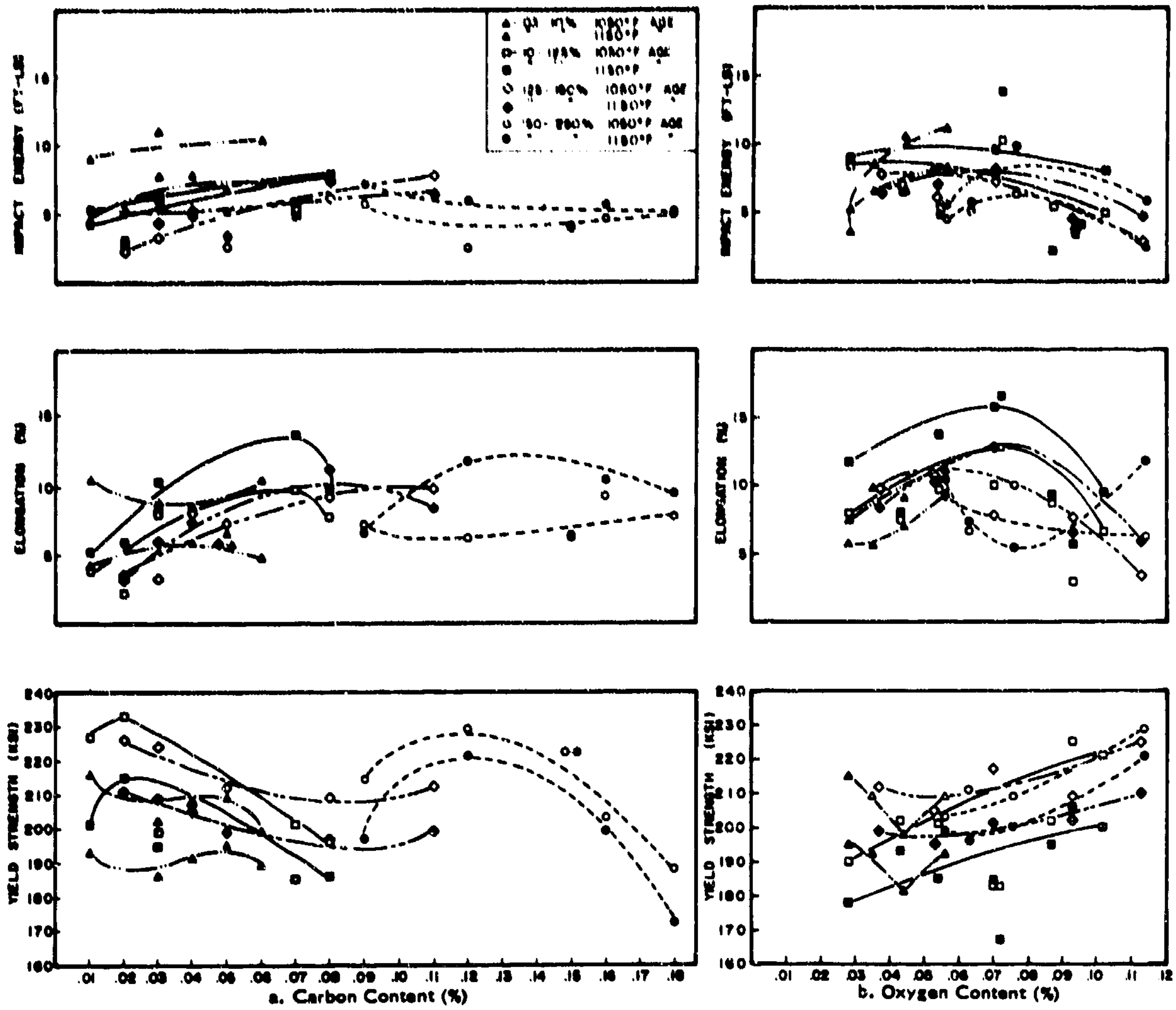

Figure 5. MECHANICAL PROPERTIES VERSUS INTERSTITIAL CONTENT

toughness exhibit a maxima between the range 0.04% to 0.06% oxygen, and decrease uniformly on both sides of this range. The ductility and toughness is considerably affected by the increase in oxygen.

Examining the yield strength curves in Figure 5a, it can be seen that the trend is for a negative slope for the first three groups as the carbon is increased to the range of 0.06% to 0.08%, and the oxygen decreased from around 0.10% to 0.05%, indicating a decline in yield strength. Correspondingly, the ductility and toughness increased. In the fourth group (0.15% to 0.25% interstitial range), however, a slightly different behavior existed. The alloys with the higher interstitial level have, as a group, less amount of beta alloying elements, but still attained higher strengths with less change in ductility and toughness. The inference was that in the alloys studied, normal amounts of oxygen (0.10% to 0.12%), when alloyed in titanium with up to at least 0.12% carbon, will increase the yield strength substantially without affecting the ductility and toughness to any great extent.

Indications in Figure 5b are that the alloys with the higher oxygen and lower carbon contents possessed higher strengths with the exception of alloy 7. The discontinuity in the curves seemed to occur when the alloys contain about 0.04% to 0.06% oxygen and insufficient carbon to replace the strengthening effect of the missing oxygen. In contrast to the plots shown in Figure 5a, the curves plotted in Figure 5b were more related with the exception of the lowest interstitial level. Here again some points were present which were not consistent with the general pattern of the curves.

Other irregularities encountered in the curves shown in Figure 5 are undoubtedly attributed to some of the alloying elements such as Mo, V, Cr, Ni, and Zr. It has been established that these elements do alter mechanical properties to varying degrees, depending on the amount present. However, for the purpose of this report, those changes which did occur have been considered secondary to the behavior of carbon and oxygen. Since properties of the alloys containing these elements were averaged in most instances with others not containing them, many changes in mechanical properties attributed to these elements were minimized.

There appeared evidence to indicate the potentiality of using increasing amounts of carbon to obtain high mechanical properties in certain yield strength ranges, as an alternate for beta substitutional elements. This is shown in Table III. The ten alloys listed had the nominal composition Ti-6Al-6V-2Sn-3Zr-1Fe-1Cu plus 1% Cr and 1% Mo additions to the last five alloys. The oxygen content of the first five alloys averaged 0.071% and in the next five alloys averaged 0.068%. The carbon content averaged 0.10% for the less complex group and 0.04% for the second group. It was apparent that the influence of up to 0.06% additional carbon was similar to 1% Cr plus 1% Mo additions in obtaining comparable mechanical properties in the 200,000 psi strength range.

CONCLUSIONS

A review of the alloys up to Alloy 30 indicated that those alloys with the extremely low oxygen content of approximately 0.03% to 0.05% generally possessed lower strengths but good ductility and toughness at comparable strength levels. The alloys with the lower oxygen content also responded more readily to the 1150 F aging treatment, causing the yield strength to decrease more substantially than those alloys in the higher oxygen content range of 0.09% to 0.11%. The remaining alloys, 31 to 56, which contained between 0.04% to 0.08% oxygen and slightly higher than normal carbon, ranging from 0.05% to 0.09%, except for Alloys 44, 45, 46 which contained 0.15% to 0.18% carbon, exhibited no definite trends.

It was noted that a combination of 0.12% carbon and 0.11% oxygen in Alloy 7 displayed a yield strength of approximately 220,000 psi, elongation of 11.9%,

Table III. MECHANICAL PROPERTY EVALUATION OF THE Ti-Al-V-Sn-Zr SYSTEM VERSUS THE Ti-Al-V-Sn-Zr-Mo-Cr SYSTEM

Alloy	Chemistry (Wt. %)		1050 F Aging Temperature			1150 F Aging Temperature		
	C	O	Y.S. (ksi)	Elon (%)	Impact Energy -40 F (ft-lb)	Y.S. (ksi)	Elon (%)	Impact Energy -40 F (ft-lb)
Ti-Al-V-Sn-Zr Alloys								
5	0.03	0.09	207	4.6	4.8	194	9.5	8.0
7	0.12	0.114	229	6.3	2.5	221	11.9	5.9
8	0.11	0.036	212	9.8	7.7	199	8.4	6.4
42	0.09	0.061	226	4.2	4.4	196	6.1	5.7
44	0.16	0.056	203	9.2	4.6	199	10.4	5.6
Average			215	6.8	4.8	202	9.3	6.3
Ti-Al-V-Sn-Zr-Mo-Cr Alloys								
1	0.04	0.093	206	8.7	5.7	205	6.2	5.0
2	0.04	0.036	206	8.5	8.4	191	13.3	10.4
21	0.01	0.102	221	6.8	5.0	200	9.6	8.1
22	0.04	0.035	210	6.3	4.0	186	11.9	8.0
50	0.08	0.07	217	7.9	7.2	202	12.8	8.1
Average			212	7.6	6.1	197	10.8	7.9

and impact strength of 5.9 ft-lb at 1150 F aging temperature. Since no explanation could be made at this time as to why the carbon and oxygen produced this high combination of mechanical properties, further studies should be conducted on a series of similar alloys containing the normal oxygen and high carbon content. When the carbon contents of the alloys were plotted against the mechanical properties, only moderate influences were seen in the ductility and toughness as compared to the considerable modification in the same properties brought about by the oxygen content.

It can also be concluded that an increase in the carbon content can be used as an alternate for small amounts of beta substitutional elements such as Cr and Mo and still obtain comparable results. However, a general conclusion encompassing all the alloys examined would be that the combination of oxygen plus carbon required to obtain optimum mechanical properties becomes a function of the alloy composition itself and the desired yield strength range.

APPENDIX A. TABLES OF MECHANICAL PROPERTIES

Table A-I. MECHANICAL PROPERTIES ARRANGED ACCORDING TO PERCENTAGE CARBON

			Aging Temperature					
			1050 F			1150 F		
Alloys	Carbon	Oxygen	Y.S. (ksi)	Elon. (%)	Impact Energy, -40 F (ft-lb)	Y.S. (ksi)	Elon. (%)	Impact Energy, -40 F (ft-lb)
16	0.01	0.034	213	3.3	5.6	192	10.9	9.9
26	.01	.036	222	1.1*	3.6	197	10.4	7.0
28	.01	.036	214	5.3	4.7	191	10.3	9.8
Average	.01	.035	216	4.3	4.6	193	10.5	8.9
6X	.03	.033	190	9.7	12.6	175	14.6	13.7
10	.03	.042	198	7.5	5.0	182	7.8	12.2
31*	.03	.051	220	1.5	3.0	209	1.3	3.2
32	.03	.058	209	9.6	8.6	195	10.2	10.5
39	.03	.053	208	8.9	7.8	192	11.9	10.1
49*	.03	.048	179	16.0	13.3	158	18.3	17.6
56	.03	.049	206	6.1	5.1	186	9.3	8.6
Average	.03	.047	202	8.4	7.8	186	8.8	11.0
2	.04	.036	206	8.5	8.4	191	13.3	10.4
4	.04	.036	206	4.9	4.8	193	12.6	8.5
12	.04	.033	206	2.0*	3.0*	193	4.1	4.2
18	.04	.034	222	5.7	3.2	197	3.9	4.4
20	.04	.041	189	7.8	9.0	175	10.2	10.7
22	.04	.035	210	6.3	4.0	186	11.9	8.0
24	.04	.036	220	2.2	2.4	200	3.7	8.7
Average	.04	.036	208	5.9	5.3	191	8.5	7.8
30	.05	.028	215	5.8	5.1	195	7.5	3.3
41	.05	.038	202	5.7	8.2	194	5.5	6.8
Average	.05	.033	209	5.8	6.7	195	6.5	5.1
14	.06	.036	199	4.7	7.2	189	10.4	10.3
13	.01	.098	219	2.6	4.8	193	3.0	3.7
21	.01	.102	221	6.8	5.0	200	9.6	8.1
27	.01	.091	240	2.3	3.4	215	3.3	3.7
Average	.01	.097	227	3.9	4.4	203	5.3	5.2
11	.02	.096	230	1.4	2.8	219	5.5	2.9
25	.02	.094	235	3.0	3.3	210	6.4	2.5
Average	.02	.095	233	2.2	3.1	215	6.0	2.7
3	.03	.087	202	8.8	5.4	195	9.1	2.3
5	.03	.090	207	4.6	4.8	194	9.5	8.0
15	.03	.092	219	4.1	2.5	206	7.0	4.0
47	.03	.073	183	12.8	10.5	167*	16.5*	13.9*
54	.03	.070	183	10.0	7.7	186	15.8	9.6
55*	.03	.081	176	14.6	12.0	159	19.1	17.5
Average	.03	.082	199	8.1	6.2	195	10.4	6.0

*Not included in average

Table A-I. MECHANICAL PROPERTIES ARRANGED ACCORDING TO PERCENTAGE CARBON (continued)

Alloys	Carbon	Oxygen	Aging Temperature 1050 F Y.S. (ksi)	1050 F Elon. (%)	1050 F Impact Energy, -40 F (ft-lb)	1150 F Y.S. (ksi)	1150 F Elon. (%)	1150 F Impact Energy, -40 F (ft-lb)
40	0.07	0.054	201	9.8	5.3	185	13.8	4.9
35	.08	.028	190	7.9	8.4	178	11.7	9.0
37	.08	.043	202	7.5	6.9	193	7.9	6.6
Average	.08	.036	196	7.7	7.7	186	9.8	7.8
9	.02	.113	226	3.6	2.3	211	3.2	5.2
19	.03	.113	224	3.3	3.3	209	6.0	4.4
1	.04	.093	206	8.7	5.7	205	6.2	5.0
23	.04	.092	208	7.5	4.0	204	8.5	5.3
Average	.04	.093	207	8.1	4.9	205	7.4	5.2
17	.05	.094	203	9.2	2.1	196	4.8	3.9
29	.05	.092	220	5.3	3.1	202	6.8	2.8
Average	.05	.093	212	7.3	2.6	199	5.8	3.4
34	.08	.051	216	1.3*	4.7	203	6.6	6.4
43	.08	.055	194	10.7	7.4	186	13.8	7.5
50	.08	.070	217	7.9	7.2	202	12.8	8.1
Average	.08	.059	209	9.3	6.4	197	11.1	7.3
8	.11	.036	212	9.8	7.7	199	8.4	6.4
38*	.11	.037	207	1.8	3.2	208	3.5	2.9
Average	.11	.036	212	9.8	7.7	199	8.4	6.4
33	.09	.076	209	8.7	6.6	200	5.4	9.9
36	.09	.064	202	6.6	4.9	186	5.2	5.5
42	.09	.061	226	4.2	4.4	196	6.1	5.7
48	.09	.063	218	8.8	7.0	206	9.8	8.1
Average	.09	.066	214	7.1	5.7	197	6.6	7.3
7	.12	.114	229	6.3	2.5	221	11.9	5.9
46	.15	.063	222	6.5	4.0	222	6.3	3.9
44	.16	.056	203	9.2	4.6	199	10.4	5.6
45	.18	.066	188	7.7	5.2	172	9.5	5.1

*Not included in average

Table A-II. MECHANICAL PROPERTIES ARRANGED ACCORDING TO PERCENTAGE OXYGEN

Alloys	Oxygen	Carbon	Aging Temperature 1050 F Y.S. (ksi)	1050 F Elon. (%)	1050 F Impact Energy, -40 F (ft-lb)	1150 F Y.S. (ksi)	1150 F Elon. (%)	1150 F Impact Energy, -40 F (ft-lb)
30	0.028	0.05	215	5.8	5.1	195	7.5	3.3
16	.034	.01	213	3.3	5.6	192	10.9	9.9
26	.036	.01	222	1.1*	3.6	197	10.4	7.0
28	.036	.01	214	5.3	4.7	191	10.3	9.8
6X	.033	.03	190	9.7	12.6	175	14.6	13.7
2	.036	.04	206	8.5	8.4	191	13.3	10.4
4	.036	.04	206	4.9	4.8	193	12.6	8.5
12	.033	.04	206	2.0*	3.0*	193	4.1	4.2
18	.034	.04	222	5.7	3.2	197	3.9	4.4
22	.035	.04	210	6.3	4.0	186	11.9	8.0
24	.036	.04	220	2.2	2.4	200	3.7	8.7
41	.038	.05	202	5.7	8.2	194	5.5	6.8
14	.036	.06	199	4.7	7.2	189	10.4	10.3
Average	.035	.034	209	5.6	6.5	192	9.7	8.5
10	.042	.03	198	7.5	5.0	182	7.8	12.2
56	.049	.03	206	6.1	5.1	186	9.3	8.6
49*	.048	.03	179	16.0	13.3	158	18.3	17.6
20	.041	.04	189	7.8	9.0	175	10.2	10.7
Average	.044	.033	198	7.1	6.4	181	9.1	10.5
31*	.051	.03	220	1.5	3.0	209	1.3	3.2
32	.058	.03	209	9.6	8.6	195	10.2	10.5
39	.053	.03	208	8.9	7.8	192	11.9	10.1
Average	.056	.03	209	9.3	8.2	194	11.1	10.3
35	.028	.08	190	7.9	8.4	178	11.7	9.0
37	.043	.08	202	7.5	6.9	193	7.9	6.6
40	.054	.07	201	9.8	5.3	185	13.8	4.9
54	.070	.03	183	10.0	7.7	186	15.8	9.6
47	.072	.03	183	12.8	10.5	167	16.5	13.9
55*	.081	.03	176	14.6	12.0	159	19.1	17.5
3	.087	.03	202	8.8	5.4	195	9.1	2.3
Average	.087	.03	202	8.8	5.4	195	9.1	2.3

*Not included in Average

Table A-II. MECHANICAL PROPERTIES ARRANGED ACCORDING TO PERCENTAGE OXYGEN (continued)

Alloys	Oxygen	Carbon	Aging Temperature 1050 F Y.S. (ksi)	1050 F Elon. (%)	1050 F Impact Energy, -40 F (ft-lb)	1150 F Y.S. (ksi)	1150 F Elon. (%)	1150 F Impact Energy, -40 F (ft-lb)
13	0.098	0.01	219	2.6	4.8	193	3.0	3.7
27	.091	.01	240	2.3	3.4	215	3.3	3.7
11	.096	.02	230	1.4	2.8	219	5.5	2.9
25	.094	.02	235	3.0	3.3	210	6.4	2.5
5	.090	.03	207	4.6	4.8	194	9.5	8.0
15	.092	.03	219	4.1	2.5	206	7.0	4.0
Average	.093	.02	225	3.0	3.6	206	5.8	4.1
21	.102	.01	221	6.8	5.0	200	9.6	8.1
8	.036	.11	212	9.8	7.7	199	8.4	6.4
38*	.037	.11	207	1.8	3.2	208	3.5	2.9
Average	.037	.11	212	9.8	7.7	199	8.4	6.4
34	.051	.08	216	1.3*	4.7	203	6.6	6.4
43	.055	.08	194	10.7	7.4	186	13.8	7.5
Average	.053	.08	205	10.7	6.1	195	10.2	7.0
50	.070	.08	217	7.9	7.2	202	12.8	8.1
1	.093	.04	206	8.7	5.7	205	6.2	5.0
23	.092	.04	208	7.5	4.0	204	8.5	5.3
17	.094	.05	203	9.2	2.1	196	4.8	3.9
29	.092	.05	220	5.3	3.1	202	6.8	2.8
Average	.093	.05	209	7.7	3.7	202	6.6	4.3
9	.113	.02	226	3.6	2.3	211	3.2*	5.2
19	.113	.03	224	3.3	3.3	209	6.0	4.4
Average	.113	.03	225	3.5	2.8	210	6.0	4.8
44	.056	.16	203	9.2	4.6	199	10.4	5.6
36	.064	.09	202	6.6	4.9	186	5.2	5.5
42	.061	.09	226	4.2	4.4	196	6.1	5.7
48	.063	.09	218	8.8	7.0	206	9.8	8.1
46	.063	.15	222	6.5	4.0	222	6.3	3.9
45	.066	.18	188	7.7	5.2	172	9.5	5.1
Average	.063	.12	211	6.8	5.1	196	7.4	5.7
33	.076	.09	209	8.7	6.6	200	5.4	9.9
7	.114	.12	229	6.3	2.5	221	11.9	5.9

*Not included in Average

LITERATURE CITED

1. FARRAR, P. A., and MARGOLIN, H. *Development of Tough, High-Strength Titanium - Base Alloys of the Ti-Al-V-Sn-X Systems.* Final Report on Contract No. DA-30-069-ORD-2480, April 1960.

2. OGDEN, H. R., and JAFFEE, R. I. *The Effects of Carbon, Oxygen and Nitrogen On the Mechanical Properties of Titanium and Titanium Alloys.* TML Report No. 20, October 19, 1955.

3. WOOD, R. *The Effect of Interstitials on the Mechanical Properties of Titanium and Its Alloys.* Paper presented at Titanium Metallurgy Course, New York University, September 13-15, 1965.

4. FARRAR, P. A., and MARGOLIN, H. *Development of Tough, High Strength Alpha-Beta Titanium Base Alloys at 240,000 to 260,000 psi Yield Strength Level.* Quarterly Progress Report No. 2 on Contract DA-30-069-ORD-3690, Technical Report WAL TR 401/303-1, December 1962.

5. FARRAR, P. A., and MARGOLIN, H. *Development of Tough, High Strength Alpha-Beta Titanium Base Alloys at 240,000 to 260,000 psi Yield Strength Level.* Quarterly Progress Report No. 3 on Contract DA-30-069-ORD-3690, Technical Report WAL TR 401/303-2, March 1963.

6. FARRAR, P. A., and MARGOLIN, H. *Development of Tough, High Strength Alpha-Beta Titanium Base Alloys at 240,000 to 260,000 psi Yield Strength Level.* Quarterly Progress Report No. 4 on Contract DA-30-069-ORD-3690, Technical Report WAL TR 401/303-3, June 1963.

7. FARRAR, P. A., and MARGOLIN, H. *Development of Tough, High Strength Alpha-Beta Titanium Base Alloys at 240,000 to 260,000 psi Yield Strength Level.* Quarterly Progress Report No. 8 on Contract DA-30-069-ORD-3690, Technical Report WAL TR 401/303-8, September 1964.

8. FARRAR, P. A., and MARGOLIN, H. *Development of Tough, High Strength Alpha-Beta Titanium Base Alloys at 240,000 to 260,000 psi Yield Strength Level.* Quarterly Progress Report No. 9 on Contract DA-30-069-ORD-3690, Technical Report WAL TR 401/303-9, December 1964.

9. *Titanium Alloy, Wrought, Rods, Bars and Billets.* Military Specification MIL-T-46038(ORD), March 18, 1960.

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13. ABSTRACT An examination was made of the alloys formulated and studied at New York University under Contract DA-30-069-ORD-3690 to determine the effect of modifying the oxygen and carbon contents normally employed in titanium alloys on their mechanical properties.

A total of 51 exploratory ultrahigh-strength alpha-beta titanium alloys were scrutinized. The results indicated that the alloys with low oxygen content, approximately 0.03% to 0.05% by weight, generally possessed lower yield strengths but good ductility and toughness compared to the alloys with higher oxygen contents at 200,000 psi strength levels. The alloys with the lower oxygen content also responded more readily to the 1150 F aging treatment, causing the yield strength to decrease more substantially than those alloys in the higher oxygen content range of 0.09% to 0.11%. The alloys containing 0.04% to 0.08% oxygen and 0.05% to 0.09% carbon exhibited no definite or predictable change in mechanical properties due to the modified oxygen and carbon. The influence of carbon on ductility and toughness was considerably less than that of oxygen. The optimum alloy, No. 7, containing 0.12% carbon and 0.11% oxygen, displayed a yield strength of approximately 220,000 psi, elongation of 11.9%, and impact strength of 5.9 ft-lb at 1150 F aging temperature.

The most effective oxygen plus carbon content for each alloy which would develop the optimum mechanical properties appeared to depend on the alloy and the specified yield strength range. (Authors)

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